INDUCTION.

BY

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With the Author's Compts
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THE first indication that such an independent power as Electricity existed in nature, was accidentally discovered by an effect which we now term Static Induction; and the only means of developing electricity previous to the commencement of the present century was by its static inductive effect; and it is now by magnetic induction that we produce strong electrical currents.

Induction is known in its Static, Magnetic, Magneto-electric, Voltaic, and Terrestrial Magneto-electric form; but its influence is not always recognised, and then it is often the cause of much confusion and perplexity to the careful investigator. Faraday believed it to be "the essential function both in the first development and consequent phenomena of Electricity," therefore how essential it is that we should possess all possible knowledge concerning it!

Soon after Faraday's important discovery of what he named Volta Induction, many gentlemen further investigated the subject, amongst whom were Professors Henry and Felice. The former constructed helices of various lengths and thicknesses of insulated metal ribbon or wire, six of which he marked respectively A, B, C, D, E, and F as shown in figure 1. One end of A was connected

to one pole of a battery, and the other end he passed rapidly over a rough file in connection with the other pole. Under these conditions, if coil B were placed over A, currents would be induced in B, and if the ends of B were connected to those of C, and coil D placed over C, then currents would be induced in D; and in a similar manner coil E would induce currents in F. Professor Henry obtained shocks from coil B when placed at a distance of four feet from A, and found that though the partition wall of two rooms intervened, the results were in no way interfered with. He also stated that by interposing a screen of any conducting substance between A and B only very slight secondary currents could be obtained, and asserted that a circular plate of lead, for instance, caused the induction in B almost entirely to disappear. It is possible that this statement may have suggested the many proposals which have been made from time to time, for lessening the induction in conductors used for telegraphic purposes, by covering them with metal; but I think I shall be able to demonstrate that there is not the advantage to be derived from such a system, as the results published by Professor Henry would lead us to expect.

Professor Felice conducted a series of well devised experiments, by a method in which the electromotive force in the galvanometer circuit was rendered zero. He arranged in pairs, four helices of precisely the same construction as shown in figure 2; and joined the two bottom helices together in circuit with a battery and simple make and break arrangement. The two top helices in circuit with a galvanometer were so connected that the inductive effect produced in coil B by A was neutralized by that produced in D by coil C, consequently no induced current would be indicated by the galvanometer on making or breaking the battery circuit. Professor Hughes has recently shown what a delicate

balance an arrangement of this kind becomes when the galvanometer is replaced by a telephone.

Each investigator appears to have had his own theory with regard to induction. Faraday believed it to be, in all cases, an action of contiguous particles in a state of polarization; whilst others considered it an action at a distance, and in straight lines. According to Faraday's view it can only take place through the influence of intervening matter, and to the present time no knowledge has been obtained which could call in question the correctness of that theory.

It is now nearly thirty years since Faraday gave me my first practical illustration of Volta Induction. On that occasion, two half-mile coils of copper wire covered with gutta-percha were placed one on the other, in the same manner as the ribbon coils A and B in figure 1. The ends of the top coil were joined direct to a galvanometer, and one end of the bottom coil to one pole of a battery, the other pole being connected to a short wire which the professor held in one hand, whilst in his other was the remaining end of the bottom coil so that the battery circuit could be closed or broken at will. It was most instructive, at least to me, to see that each time the battery circuit was made, the magnet of the galvanometer in connection with the top coil was momentarily deflected, returning at once to its normal position, where it remained until the circuit was broken, when the magnet was again deflected but in the opposite direction, returning as before to zero. By judiciously making and breaking the battery circuit in harmony with the swing of the magnet, the deflections soon became very extensive. It was also very instructive to watch the continual decrease in the range of the galvanometer deflections, as the coils were gradually removed one from the other, until the distance became too great for the magnet to be visibly affected. Then by removing

the two ends of the coil from the galvanometer and applying them to the tongue, the inductive effects could still be detected until the coils were separated too far for even this delicate test. The professor, in his usual kind and simple manner, impressed on me the importance of not supposing that the effects of induction had ceased because he was no longer able to prove their existence, for he believed that there was no distance so great, but that induction could take place through it. I can imagine with what satisfaction, he would have employed in his experiments on induction, that wonderfully sensitive instrument the telephone; which would have enabled him to have demonstrated, that although vision and taste had failed, the ear would still be able to detect sounds produced by induction though the coils were fifty feet apart, or the battery power reduced to the $\frac{1}{100,000}$ part of a volt.

Professor Faraday's experiment returned vividly to my mind during the laying of the submarine cable between Brest and St. Pierre, in the summer of 1869. The total length of that cable, 2755 nautical miles, was coiled into three tanks on board the S.S. *Great Eastern.* The laying commenced from Brest, and when communication was established between ship and shore through the entire length of the cable, it was noticed that each current sent from shore produced two distinct signals on the scale of the mirror-reflecting galvanometer used as the receiving instrument on board. On investigating the cause of this singular phenomenon, it was found to proceed from the way in which the cable was coiled; the first signal being the effect of induction, which always manifested itself an appreciable time before the appearance of the true signal. This will be readily understood by reference to figure 3, where it will be seen that the induction was caused by the 245 miles of the out-going part of the cable being coiled on the top of the last

portion of the cable in the main tank. As the cable forming the top coil was being paid out, the amplitude of the induction signal gradually diminished, but it did not entirely disappear until the last turn of the top coil was removed.

I have made from time to time, as opportunity offered, experiments with a view to determine what perhaps I may be allowed to term the "Specific Inductive Resistance" of electrics and dielectrics. I assume that the experiments of Professor Faraday are well known, by which he proved that all dielectrics had what he named Specific Inductive Capacity,—that is, he constructed what was to all intents and purposes a Leyden jar or condenser, the dielectric part of which could be with facility varied from one substance to another. By so changing them, he found that the amount of charge varied according to the dielectric employed; provided they were tested under exactly similar circumstances and that the inducing surfaces of the conductors had a constant form and state, and were at a constant distance from each other.

Now what I mean by Specific Inductive Resistance in contradistinction to Specific Inductive Capacity, will be made clear by the results of the following experiments. Two equal lengths of copper wire insulated with gutta-percha were wound side by side upon a wooden reel and immersed in water. The specific inductive capacity of each length was ·084 of a microfarad. Now, to measure what I call the specific inductive resistance of the dielectric, the two ends of one of the coils were connected to a galvanometer, and the other coil was then charged to the same potential as when measuring its specific inductive capacity. The deflection on the galvanometer caused by induction from the charge in the other coil was say = 1. Two precisely similar lengths, and of the same dimensions, but insulated by a dielectric

of known high specific inductive capacity, were then tested in the same way, and the following results obtained:—

Specific inductive capacity = ·288 microfarads.
Deflection on galvanometer = ·94 ,,

showing, the galvanometer deflection being less, that there was less inductive effect through the dielectric of high specific inductive capacity, or in other words that the specific inductive resistance was greater. It therefore follows, that for the dielectric of a long line of telegraph, either submarine or subterranean, where one conductor is alone employed the dielectric of the lowest specific inductive capacity is the most suitable; but where it is desirable to lessen as much as possible, induction between parallel wires in close proximity, and of comparatively short lengths, then the dielectric of the highest specific inductive capacity would be the more suitable of the two.

In my endeavours to ascertain the true specific inductive resistance of electrics and dielectrics, I had constructed two flat spirals of fine silk-covered copper wire about 12 inches each in diameter, and suspended spider-web fashion in separate wooden frames; the two ends of each spiral being brought down and attached to terminals at the base of its own frame. The two frames were then placed in a vertical position opposite to each other, and at a convenient distance apart. The end of one spiral led to one pole of a battery of six Leclanché cells, the other pole of the battery being in connection with the wire of a small electro-magnet fixed between the prongs of a tuning fork; the remaining end of the wire of the magnet was attached to the fork itself, one arm of which impinged upon a contact screw connected to the other end of the flat spiral. There was thus formed a metallic circuit, completed by means

of the contact screw and arm of the fork. Consequently the electro-magnet influenced the arms of the fork causing them to vibrate, and thus by means of one arm vibrating against the contact screw, a rapidly intermittent current resulted, the speed of the pulsations being governed by the pitch of the fork. A telephone and suitably subdivided resistance coil were joined in circuit with the other flat spiral.

Under these conditions, the telephone reproduced very loudly the note given by the transmitter (tuning fork); the inductive lines of force emitted by the spiral in circuit with the battery and transmitter, being received and converted into corresponding intermittent currents by the flat spiral connected to the telephone.

A plate sixteen inches square and half an inch thick of the electric or dielectric under test, was placed midway between the two spirals, and then the resistance in circuit with the telephone was increased until no sound could be heard. The whole of the arrangement is shown in figure 4, A and B representing the two spirals, C the tuning fork, D the battery, E the subdivided resistance coil, F the telephone, and G the substance under test. If the spiral B were gradually moved farther from A, along a graduated scale, the effect would be the same as inserting resistance at E, and the relative values would then be obtained in units of length instead of in units of resistance. Other arrangements were also tried, but the results were so variable and capricious that no reliance could be placed on any one of them. On investigating the cause of such discrepancy, I *discovered the important fact, that the telephone was affected even when entirely disconnected from the circuit, and several feet from the inducing spiral.*

This discovery at once diverted my thoughts into other directions, and I had constructed a similar but much larger flat spiral thirty-six inches in diameter, and

supported between two square sheets of cardboard fixed in a vertical wooden frame. The wire ·018 inch in diameter and silk covered, was coiled from the centre in a direction from right to left and consisted of 800 turns with a total length of 1220 yards, and resistance of 122 ohms. If such a spiral be placed in the centre of a large room, sounds such as speech or music affecting the transmitter can be distinctly heard in every part of the room by any person placing a disconnected telephone to his ear, provided of course that his hearing is not seriously defective, and that the telephone is held in a favourable position with regard to the inductive lines of force.

The direction of the lines of force emitted from the flat spiral is such, that starting from any point on one of its faces a circle is described extending to a similar point on the opposite side. The diameter of the circles described decrease from infinity as the points from which they start recede from the centre towards the circumference. From points near the circumference the circles or curves are very small. If a small flat spiral, the ends of which are connected to a telephone, be placed in the neighbourhood of the exciting spiral, a sound is heard in the telephone, the intensity of which depends not only upon the distance of the small spiral from the exciting one, but upon the position in which it is placed relatively to the lines of force; the sound being at its maximum when at right angles thereto, and gradually decreasing to zero as the small spiral is slowly turned until the plane of the spiral is parallel to the lines of force. By taking advantage of this fact their direction was mapped out as shown in figure 5.

It was found by experiment that if the small flat spiral in connection with the telephone be moved from the centre of the large exciting one towards its circumference, for instance, along the line A B, figure 5, then

the intensity of the sound produced in the telephone slowly diminishes as the small spiral is moved from the centre, but on approaching a point near the outer edge, the sound rapidly falls to zero, increasing again as the spiral is moved beyond the silent point. The reason for this is plainly shown by figure 5, for it will be seen that when the small spiral is in the centre of the exciting one, it is cut at right angles by the lines of force, but as it is removed from the centre it is cut more and more obliquely till at the point C, near the circumference, the lines of force are parallel to the small spiral and consequently no sound is heard. It is also self-evident that, starting from any point on one side of the exciting spiral, the small spiral may be moved in a complete circle till the opposite face be reached without producing sound, the diameter of such circle depending upon the distance of the point chosen from the centre. It is not absolutely necessary to have a small spiral of wire attached to the telephone in tracing the directions of the lines of force, as the telephone by itself is all sufficient, and more convenient when following the lines at a distance from their source. Neither is it necessary for a coil of wire to be on the magnet as in ordinary telephones, for the best effects are obtained when the magnet and thin iron diaphragm are alone used: the iron diaphragm by itself will emit the sound, or the magnet by itself; but neither separately are so efficient as when placed together as in an ordinary telephone. With a magnet and copper diaphragm sound can be plainly heard, and apparently all metals are capable, to a greater or less extent, of converting inductive vibrations into sound. If the coil be allowed to remain on the magnet, care must be taken that it is not "short circuited" or no sound will be produced, no matter in what position the telephone is held.

If a flat spiral be placed a certain distance in front of the exciting one, and a similar spiral be placed an

equal distance behind, then, on connecting the two outer or inner ends together and the remaining two to a telephone, no sound is heard, for the effect produced in one spiral is equal and opposite to that produced in the other, thus a perfect balance may be obtained. But if the outer end of one spiral be joined to the inner end of the other and the remaining ends to a telephone, then a very loud sound is produced, and no balance can be obtained, for the effect of one is added to the effect of the other. In the same way, one spiral placed in front of the exciting one may be made to balance two or more placed behind, but in this case, the two or more must, to compensate for their number, be placed at a greater distance, or more obliquely to the lines of force.

With the object of ascertaining whether the inductive lines of force given out from one source would in any way interfere with those proceeding from another, a similar spiral to the large one already described was placed parallel to it at a distance of three feet; they were then connected to independent batteries and transmitters, each transmitter having a sound perfectly distinct from that of the other. When the circuits were completed, the separate sounds given out by the two transmitters could be distinctly heard at the same time on the same telephone; but by placing a telephone in a position neutral to one of the spirals, then only the sound proceeding from the other could be heard. Thus if two ordinary Morse keys were substituted, one for each transmitter, and words in the Morse code sent by the same, then a person holding a telephone in a position neutral to one spiral would read only what was being sent on the other.

Thus in diagram 6, A and B are the two spirals fixed in their stands, and C and D the telephones; then if C be placed in the position indicated, it would

be neutral to the lines of force emanating from A but influenced by spiral B, in the same way D would be neutral to B but influenced by A. These results occur in whatever positions the spirals are placed relatively to each other, thus proving that there is no interference or blending of the separate lines of force.

Many and varied are the experiments suggested by this discovery, but here for a time I must leave it; and in so doing sincerely hope that sufficient has been shown, to induce others to further experiment in the same direction.

Returning to my researches on Specific Inductive Resistance, the arrangement shown in figure 4 was replaced by that of figure 7, in which A, B, and C represent three similar flat wire spirals, A and B being fixed a suitable distance apart and C so arranged that it could be moved along a scale, each inch of which was divided into one hundred parts. B was in circuit with a tuning fork transmitter D and battery E, whilst spirals A and C were joined in circuit with a telephone F as shown; *viz.*, with their two inner ends connected together, and their outer ends to the telephone. When the spirals A and C were at equal distances one on either side of B, no sound could be heard in the telephone, the inductive effect produced upon A by B being neutralized by that produced upon C. But when a plate of metal or other substance of low electrical resistance intercepted the lines of force between A and B, as shown at G, then sounds were immediately heard in the telephone; and so long as the plate remained in that position no zero could be established.

It was, however, observed while withdrawing the spiral C farther from B, that, at a certain distance a point was reached which gave a minimum sound; but as nearly the same distance appeared to apply to all

the metals tried, it would have been extremely difficult, if not impossible, to have obtained accurate measurements by this arrangement.

The degree of loudness of the *minimum sound* referred to, varies with each metal, copper for instance having a very faint sound, whilst that of iron and steel being much louder.

Other means were therefore sought for, and successfully found in the arrangement represented in figure 8, in which A and B represent two flat spirals fixed a suitable distance apart. In circuit with A was a battery C and reverser D, and in circuit with B a similar reverser E, and an astatic mirror reflecting galvanometer F. The reversers were so arranged that E should reverse slightly in advance of D, and by that means, a large and steady deflection was obtained, the galvanometer being always affected in the same direction by the induced currents set up in B. A plate of the substance to be tested was then placed midway between the spirals as shown at G, and in proportion to the interception of the lines of force so were the deflections on the galvanometer; and thus, by this arrangement, very accurate and sensitive measurements could be made. By this method the following results were obtained, showing the percentage of inductive radiant energy intercepted by plates of metal sixteen inches square and half an inch thick.

TABLE I.

	INTERCEPTION PER CENT.
Copper	44·1
Tin	3·5
Lead	·4
Zinc	11·9
Steel	55·3
Iron	57·0
Compressed Iron filings	10·0

It was observed that time was an important element to be taken into account whilst testing the above metals, that is to say, the lines of force took an appreciable time to polarize the particles of the metal placed in their path, after having accomplished which they passed more freely through the same. That being so, the thought naturally occurred, *Would the results be effected by varying the speed of the reversers, so as to increase the number of the lines of force striking the plate under test in a given time?* The results given in the following table, clearly show that this surmise was correct; and the knowledge gained opens out another large field for earnest thought and further investigation.

TABLE II.

Metal under Test.	Per cent. of Inductive Energy intercepted for various speeds. Number of Reversals per Minute.							Conductivity of the Metal pure Copper = 100.
	384.	432.	504.	560.	624.	720.	Mean.	
Copper . . .	44·1	49·6	55·2	59·4	62·1	67·5	56·3	73·0
Brass . . .	9·3	11·3	14·7	19·9	23·9	26·5	17·6	20·4
Tin . . .	3·5	7·4	7·4	9·7	11·3	13·1	8·7	17·4
Lead . . .	·4	4·0	3·0	2·8	5·0	5·2	3·4	6·4
Zinc . . .	11·9	16·1	20·2	23·6	26·0	30·9	21·4	33·3
Steel . . .	55·3	56·8	57·6	58·0	59·0	59·8	57·7	11·7
Iron . . .	57·0	58·1	57·8	58·4	59·8	60·0	58·5	13·8
Iron Filings . .	10·0	—	—	—	—	18·5	14·2	—

It will be noticed by reference to the foregoing table that the percentage of inductive energy intercepted does not increase for different speeds of the reversers, in the same ratio with different metals, the increase with iron being very slight, whilst with tin it is comparatively

enormous. The following table gives the percentage of increase for each metal experimented with:—

TABLE III.

METAL UNDER TEST.	PER CENT. OF INCREASE.
Copper	53
Brass	185
Tin	274
Lead	—
Zinc	160
Steel	8·1
Iron	5·3
Iron filings	42·

Sheets of metal similar to those in the tables, but only $\frac{1}{8}$ of an inch thick in no way intercepted the lines of force.

If for each metal the mean of the results obtained with various speeds (*see* table 2) be compared with the specific conductivity of the same, it will be seen that in each case the specific inductive resistance is in the same direction as that of their specific conductivity, with the exception of the magnetic metals iron and steel; that is to say, the higher the inductive resistance the higher the conductivity.

When two metals are combined to form an alloy, the resistance of the alloy is in most cases greater than that calculated from the resistance of the component metals and their proportions. The specific inductive resistance of alloys appears to follow in the opposite direction. For example, the percentage of inductive radiant energy intercepted by copper is 56·3, and that of zinc 21·4, but an alloy composed of sixty parts copper and forty parts

zinc only intercepted 17·6. The following will further illustrate the subject:—

Composition of Alloy.	Interception per cent.	Calculated.
67 parts Copper, 33 „ Zinc	14·6	45·6
62 „ Copper, 37 „ Zinc, 1 „ Tin	14·7	43·6

It will also be observed that the increase in the proportions of the metal copper of the highest specific inductive resistance decreases the inductive resistance of the alloy.

Dielectrics, such as gutta-percha, glass, sulphur, and shellac, as well as fluids and gases, have little or no effect in intercepting the lines of force.

It appears that under various pressures, metallic filings may be united into coherent masses. Thus it is stated that particles of bismuth formed into discs under a pressure of 6000 atmospheres, have a crystalline fracture, and a density which is the same as that of discs of the same metal formed from the molten state. It would be instructive to know if two apparently similar discs, one being formed from the molten metal, and the other of particles united under pressure, would give the same specific inductive resistance, if not, it would I think clearly prove that they were not identical in structure. It will be observed in table 2, that there is a marked difference in the specific inductive resistance between the plate of iron, and the one obtained from iron filings united under pressure. But that difference may proceed from the fact that the pressure applied was comparatively low compared to that mentioned.

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FIGURE 1.

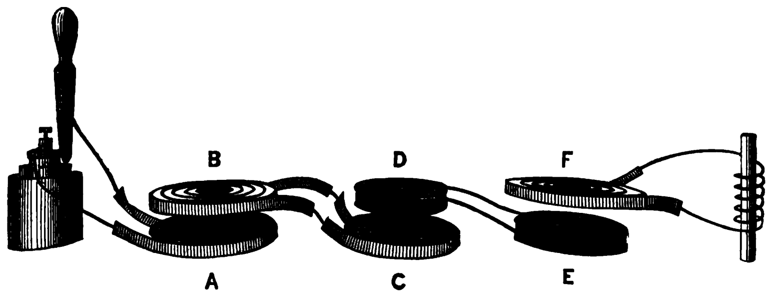

FIGURE 2.

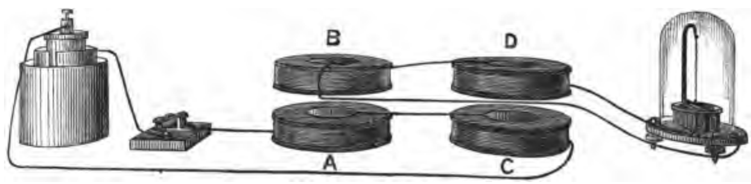

FIGURE 3.

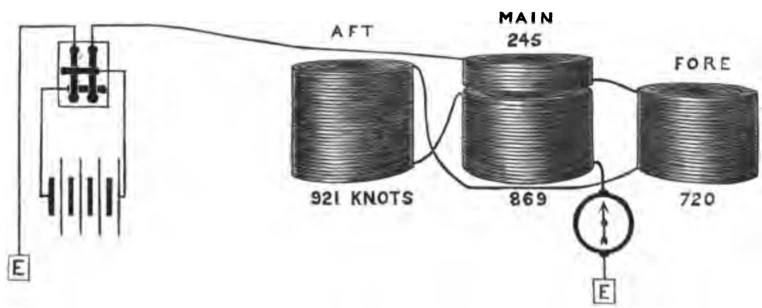

FIGURE 4.

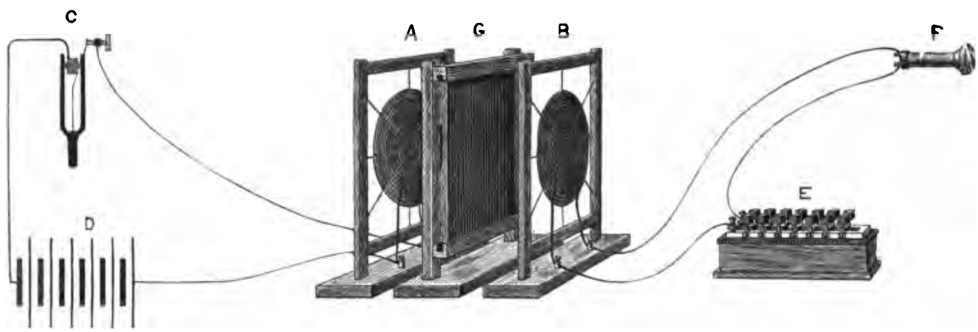

FIGURE 5.

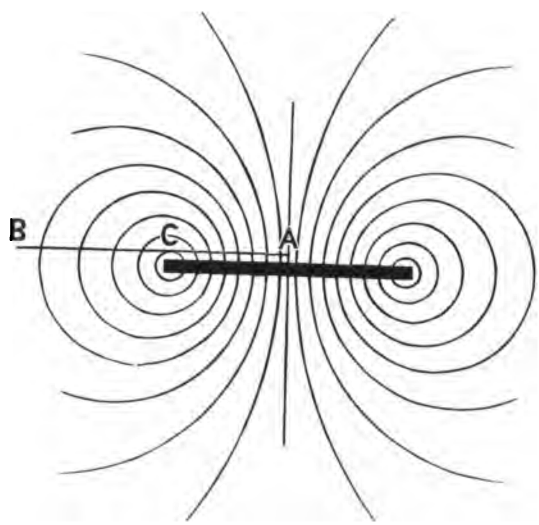

FIGURE 6.

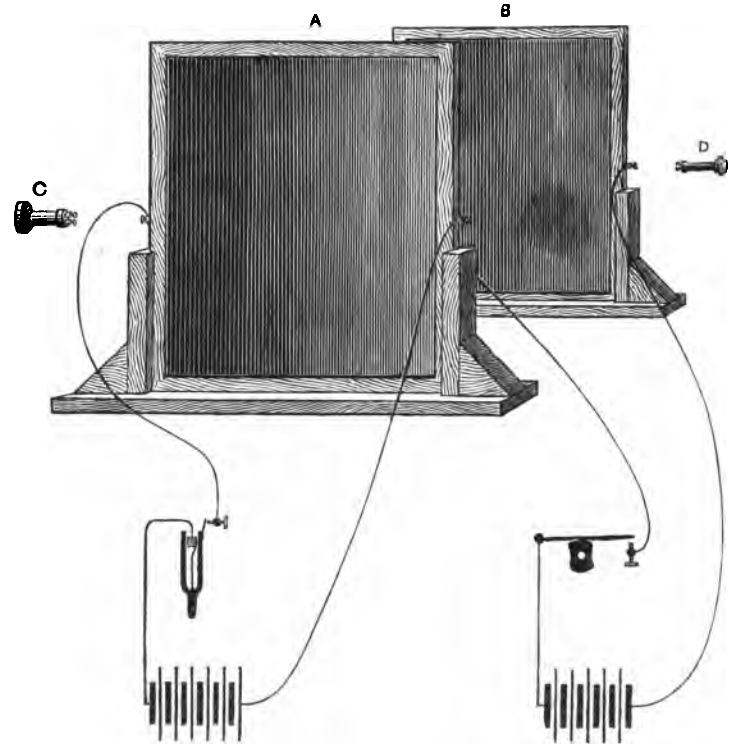

FIGURE 7.

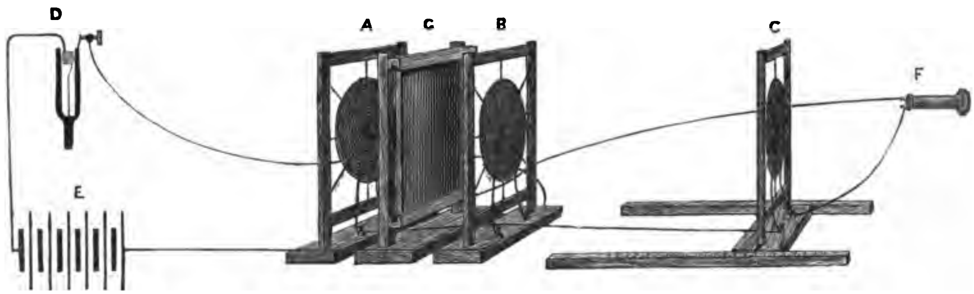

FIGURE 8.